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SONAR SENSOR ARRAY AND METHOD OF OPERATING SAME

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0003] The present invention generally relates to sonar sensor arrays and more particularly, to a sonar sensor array that has reduced power consumption, bandwidth and data storage requirements.

(2) Description of the Prior Art

[0004] Acoustic sonar sensors are used for many purposes and in a variety of environments. For example, acoustic sonar sensors are used on surface ships and also in underwater applications such as line arrays, submarines and unmanned undersea vehicles. Such acoustic sensors are used to detect ships, marine life, marine geology, and other underwater sound sources.

[0005] The acoustic sonar sensors are typically fixed in either a linear arrangement or in a structure that conforms to a

hull of a host vehicle. Current acoustic and other type sonar sensors require a fixed amount of power to operate with the result of a fixed measurement data rate for a given application. In some applications, the measured signal of interest is present for relatively short periods of time followed by relatively long periods of time in which there is no signal of interest.

[0006] Sonar sensor arrays that are configured to continuously acquire and record sensor data consume significant amounts of electrical power and utilize large amounts of available memory. In such sonar sensor arrays, all of the sensors are constantly powered since signal monitoring continuously occurs. Therefore, such sensor arrays can be very inefficient with the result of limited operating time for battery-powered systems wherein a finite amount of electrical energy is available for a given mission. Furthermore, these existing prior art sonar sensor arrays are constricted by a data playback bottleneck such that only a limited amount of playback bandwidth is available for the specific application or mission.

[0007] What is therefore needed is a sonar sensor array that addresses the problems of the aforementioned prior art sonar sensor arrays and utilizes significantly less power, bandwidth and data storage.

SUMMARY OF THE INVENTION

[0008] Accordingly, it is a general purpose and primary object of the present invention to provide a sonar sensor array that

addresses the foregoing deficiencies and disadvantages of prior art sonar sensor arrays.

[0009] It is a further object of the present invention to maximize the efficiency of the limited energy storage of battery powered sonar sensor arrays while compensating for limited playback bandwidth.

[0010] To attain the objects described, the present invention is directed to a sonar sensor array that utilizes significantly less electrical power, bandwidth and data memory. The sonar sensor array may be configured in any one of three operational modes depending on the environmental conditions and programmed system parameters.

[0011] A first mode of the three modes is a sleep mode in which all sonar sensors are turned off (not powered) and no monitoring of acoustic signals occurs. The sleep mode is used when there are significantly long periods of time between appearances of targets. A second mode is a low-resolution mode in which a limited number of sonar sensors are activated and acoustic signals are sampled and digitized using reduced bandwidth and dynamic range. One alternate embodiment is related to the functions in the signal processor versus the electronic circuits. Quite often the digitization of acoustic signals can occur in the electronic circuits.

[0012] Digitized acoustic signal data is stored on a data storage device. A third mode is a high-resolution mode in which all sonar sensors are activated and acoustic signals are sampled

and digitized with full bandwidth and full dynamic range. The digitized acoustic signal data is then stored in a data storage device.

[0013] In one embodiment, the sonar sensor array cycles between the low-resolution mode and the high-resolution mode wherein processing of the high-resolution mode does not occur unless processing of the low-resolution determines the presence of a target of interest. In another embodiment, the sonar sensor array cycles between the sleep mode and high-resolution mode. In such an embodiment, the sonar array system remains in the sleep mode for a predetermined amount of time until acoustic energy is detected in which case the sonar sensor array immediately shifts into high-resolution mode signal processing. Thus, the present invention is directed to a sonar sensor array that comprises a plurality of sonar sensors, wherein each sensor can be configured to a powered mode in which the sensor detects acoustic signals or to a sleep mode in which the sensor receives no electrical power and does not detect acoustic signals.

[0014] The sensor array further comprises a data acquisition device having a signal processor and a data storage device. The signal processor samples and digitizes the acoustic signals received by the sonar sensors and the digitized signal data is stored on the data storage device. The data acquisition device is configured to operate in a low-resolution mode of signal processing in which acoustic signals received by the sonar sensors are processed by the signal processor at a reduced bandwidth and

dynamic range, and then stored on the data storage device. The acquisition device is also configured to operate in a high-resolution mode in which the acoustic signals received by the sonar sensors are processed at full signal bandwidth and dynamic range and then stored on the storage device.

[0015] The sonar array system further comprises a control circuit for configuring the sensors to the sleep mode or to the powered mode. The control circuit also configures the data acquisition device to the low-resolution mode or to the high-resolution mode depending upon the amplitude level of the detected acoustic signals and whether the acoustic signals indicate the presence of a target of interest. During the low-resolution mode, the control circuit configures a limited number of sonar sensors to the powered mode. During the high-resolution mode, the control circuit configures all of the sonar sensors to the powered mode.

[0016] An important feature of the present invention is the utilization of known and particular characteristics of the acoustic signals and noise being measured in order to vary the operational modes of the data acquisition device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] A more complete understanding of the invention and many of the attendant advantages thereto will be appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein corresponding reference characters

indicate corresponding parts throughout the several views of the drawings and wherein:

[0018] **FIG. 1** depicts a block diagram of a sonar sensor array in accordance with one embodiment of the present invention;

[0019] **FIG. 2** depicts a flow chart of the operation of the sonar sensor array of **FIG. 1**; and

[0020] **FIG. 3** is a chart of the differences between a prior art system and the sonar sensor array of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Referring to **FIG. 1**, there is shown a sonar system **10** in accordance with one embodiment of the present invention. The system **10** comprises a line array **12** that has a plurality of sonar sensors **14**. Each sensor **14** has a corresponding electronic circuit **16** that contains a switch that, when closed, allows electrical power to be applied to the sensor so as to activate the sensor. When the sensor **14** is activated; the sensor is in the powered mode. When the switch is open, electrical power is removed from the sensor **14**; thereby, turning off the sensor. In use, the array of sonar sensors **14** could be a line array or the array of sonar sensors could be a planar array.

[0022] When the sensor **14** is off or deactivated, the sensor is in the sleep mode. Each electronic circuit **16** is capable of receiving a control signal that allows the switch to configure the corresponding sensor to the sleep mode or to the powered mode. Each electronic circuit **16** also includes an output port for

providing the acoustic signals sensed by the sonar sensor **14**. A power source **18** provides electrical power to the circuits **16** and other components of the sonar sensor array **10**. The power source **18** is typically a battery of fixed capacity.

[0023] The sonar sensor array **10** further comprises a data acquisition device **20** which samples, digitizes and records acoustic signals received from the sonar sensors **14**. The data acquisition device **20** comprises a signal processor **22** and a data storage device **24**. The signal processor **22** is in data signal communication with the data storage device **24** via a data bus **26**. The signal processor **22** samples and digitizes acoustic signals.

[0024] In one embodiment, the signal processor **22** is programmed with algorithms such as Fast Fourier Transform or Discrete Fourier Transform. The data storage device **24** may be a non-volatile memory or other suitable memory device. In a preferred embodiment, the data storage device **24** includes pre-stored data relating to known target signatures or target characteristics. In such an embodiment, the signal processor **22** compares recently processed acoustic signals with stored data that relates to known target signatures in order to determine if a particular target is or has been in the environment.

[0025] The data acquisition device **20** can be configured to a sleep mode in which some circuitry of the data acquisition device **20** is disabled to reduce electrical power consumption. In the sleep mode, no signal processing occurs and thus, no data storage space of the data storage device **24** is used. When the data

acquisition device **20** is configured to the sleep mode, all sonar sensors **14** are configured to the sleep mode with the result of significantly reducing power consumption.

[0026] The data acquisition device **20** can be configured to operate in a high-resolution mode. In the high-resolution mode, all channels (i.e., all sonar sensors **14**) are in the active or powered mode and the signal processor **22** samples and digitizes acoustic signals with full signal bandwidth and full dynamic range. All data is then stored to the data storage device **24** for later playback.

[0027] The data acquisition device **20** can be configured to a low-resolution mode. In the low-resolution mode, the electrical power and data record bandwidth are significantly reduced. In this mode, only a limited number of the sonar sensors **14** are in the powered mode. In one embodiment of the low-resolution mode, the signal bandwidth is reduced by reducing the signal sample rate, for example, by a factor of 5:1. In another embodiment of the low-resolution mode, a second data rate reduction is effected by compressing the amplitude scale of the measurement, for example by converting 24-bit linear to 8-bit compounded resolution. This achieves a reduction factor of 3:1 in data rate.

[0028] The combination of reduced bandwidth and reduced amplitude resolution has an improvement in reduced data rate by a factor of 15:1 compared to the high-resolution mode. In the low-resolution mode, data volume is also further reduced by the utilization of only a limited number of the sonar sensors **14** in

the powered mode. This is because a line array of sensors is typically designed with a physical spacing related to the upper design frequency of interest. The sonar sensor array system **10** can be configured so that only every third, or every fourth, or every fifth, etc. one of the sonar sensors **14** is configured to the powered mode while the remaining sonar sensors are configured to the sleep mode. The reduction in signal bandwidth (by a factor of 5:1 by reducing the sampling rate in combination with using a limited number of powered sensors) results in an aggregate data-rate reduction factor of 45:1 to 75:1.

[0029] The low-resolution mode may be implemented by simultaneously reducing the sampling rate and compressing the amplitude scale of measurement. The signal processor **22** is programmable and can be configured to the sleep mode, low-resolution mode or high-resolution mode upon receipt of a signal from a control circuit **30**. The sleep mode allows for a periodic time window between the high-resolution mode and the low-resolution mode, or between successive periods of high-resolution modes, in order to further reduce electrical power and is effective when the signal of interest is slowly varying over the time span of several cycles in the high-resolution mode, low-resolution mode and sleep mode.

[0030] The control circuit **30** comprises an energy detector **32**, comparison circuitry **34** and control signal circuitry **36**. A data bus **38** is in data signal communication with the signal processor **22** and the control signal circuitry **36**. A data bus **40** is in data

signal communication with the circuits **16** which are associated with the sonar sensors **14**. The control signal circuitry **36** issues digital control signals by the data bus **38** to change the mode of the signal processor **22** to the sleep, low-resolution or high-resolution modes.

[0031] In a preferred embodiment, the control signal circuitry **36** is programmable and has a data storage device such as a read-only-memory or other type of non-volatile memory for storing pre-programmed sequences of operation. The control signal circuitry **36** also outputs digital control signals over the data bus **40** to configure the sonar sensors **14** to the sleep mode or to the powered mode. The energy detector **32** detects acoustic signals received by the powered sonar sensors **14** and outputs a signal waveform **42** that represents the detected acoustic signals.

[0032] In one embodiment, the energy detector **32** comprises a frequency-selective band-pass filter and an averaging circuit. The averaging circuit produces a slowly varying signal that is proportional to the input of the band-pass filter. The pass-band of the bandpass filter is adjusted to a band of frequencies associated with a target of interest.

[0033] The comparison circuitry **34** compares the amplitude level of the signal waveform **42** to a predetermined threshold level or reference voltage. If the amplitude level of the signal waveform **42** exceeds the threshold; then a target is present and the circuitry **34** issues a signal **44** to the control signal circuitry **36** that indicates a target is present. In response, the

control signal circuitry **36** outputs a control signal over the data bus **38** that shifts the operation of the data acquisition device **20** to the high-resolution mode (in order to determine if a target signature is present) and outputs control signals over the data bus **40** to configure all sonar sensors to the powered mode.

[0034] If the amplitude level of the signal waveform **42** is less than or equal to the predetermined threshold; then a target is not present and the circuitry **34** outputs the signal waveform **42**. The signal waveform **42** indicates a target is not present. In response, the control signal circuitry **36** outputs a control signal over the data bus **38** that maintains the data acquisition device **20** in the low-resolution mode and outputs control signals to maintain a predetermined number of sonar sensors **14** in the sleep mode.

[0035] In an alternate embodiment, the sonar sensor array **10** includes additional feedback circuitry to automatically adjust or vary the predetermined threshold level or reference voltage to account for variations in ambient noise levels.

[0036] If the sonar sensor array **10** is to be configured in the sleep mode, then the control signal circuitry **36** outputs a control signal over the data bus **38** that configures the data acquisition device **20** to the sleep mode and also outputs control signals over the data bus that configure all of the sonar sensors **14** to the sleep mode.

[0037] If the sonar array system **10** is to be used in a slowly varying environment where a target of interest may be expected to appear, the control signal circuitry **36** may be programmed to

continuously cycle the data acquisition device **20** between the sleep mode and the low-resolution mode at an appropriate rate and duty cycle. In such an embodiment, the control signal circuitry **36** is programmed to periodically output control signals over the data bus **40** that powers a limited number of the sonar sensors **14**.

[0038] The energy detector **32** monitors for a pre-programmed increase in acoustic signal levels. The low-resolution mode processes the acoustic signals to determine if a target of interest is actually present. If the target is present, the control circuit **30** automatically shifts the data acquisition device **20** into the high-resolution mode to make a more precise measurement of the characteristics of the acoustic signals in order to determine if a known target signature is present. In one embodiment, the control circuit **30** is programmed to control the data acquisition device **20** so that the acquisition device cycles between the low-resolution and high-resolution modes without using the sleep mode. This embodiment is suited to environments that have slowly varying targets of interest which results in the maximum amount of relevant information being recorded but with a minimum of data volume.

[0039] Referring to **FIG. 2**, there is shown a flow chart that illustrates the operation of the sonar sensor array **10** in accordance with the invention. As a reference point, the data acquisition device **20** may be configured into the sleep mode numerous times during a period of operation (e.g., 24 hours, 48 hours, etc.). In step **60**, all of the sonar sensors **14** and the

data acquisition device **20** are in the sleep mode for a predetermined amount of time T1. Next, in step **62**, after the time T1 elapses, the control signal circuitry **36** issues a control signal to power a limited number of the sonar sensors **14** and also issues a control signal to configure the data acquisition device **20** to the low-resolution mode.

[0040] If the energy detector **32** detects acoustic signals from the powered sonar sensors **14**; the low-resolution mode processes these acoustic signals to determine if a target of interest is present. In step **64**, if it is determined that a target of interest is not present, then the control signal circuitry **36** issues control signals that configure all of the sonar sensors **14** and the data acquisition device **20** to the sleep mode. If in step **64**, it is determined that a target is present, then in step **66**, the control signal circuitry **36** issues control signals to power all of the sonar sensors **14** and to configure the data acquisition device **20** to the high-resolution mode for a predetermined amount of time T2.

[0041] In the high-resolution mode, the acoustic signals received by the sonar sensors **14** are processed to determine if a target signature is present and then recorded. If in step **68**, it is determined that a target signature is not present; the control signal circuitry **36** issues control signals that configure all of the sonar sensors **14** and the data acquisition device **20** to the sleep mode. If in step **68**, it is determined that a target signature is present, then step **70** implements a predetermined time

delay T3 and then returns to high-resolution mode processing in step **66**. The high-resolution mode processing will continue for another time segment T2. After the predetermined time segment T2 elapses, step **68** again determines if a target signature is still present.

[0042] If a target signature is still present, then step **70** initiates another time delay T3. Thus, steps **66**, **68** and **70** form a loop that continues until a target signature is no longer present; in which case the control signal circuitry **36** will shift the data acquisition device **20** and the sonar sensors **14** back to the sleep mode. The control signal circuitry **36** can be programmed to continuously cycle between the sleep mode and low-resolution mode until the processing of the low-resolution mode determines if a target of interest is present. In such an embodiment, steps **60**, **62** and **64** are repeated until step **64** determines that a target is present, in which case high-resolution processing is implemented.

[0043] The control signal circuitry **36** may be programmed to cycle the sonar array system **10** between the sleep mode and the high-resolution mode. This embodiment is suitable when there are targets of interest that are infrequent and slowly moving. In this embodiment, the high-resolution mode is activated in an intermittent manner wherein data is recorded in short segments separated by time periods in which there is no data recording. This embodiment is useful in environments where there is a high signal-to-noise ratio. In such an embodiment, the control signal circuitry **36** maintains the sonar array system **10** in the sleep mode

for a predetermined amount of time and then is configured to the high-resolution mode for a predetermined amount of time.

[0044] If the high-resolution mode processing detects a target signature, then the system will enter the loop defined by steps **66**, **68** and **70**. If the high-resolution processing does not detect a target signature, the control signal circuitry **36** configures the sonar sensors **14** and the data acquisition device **20** to the sleep mode. The control signal circuitry **36** will continue this pattern in accordance with a pre-stored program of operation.

[0045] The present invention is significantly more efficient than prior art sonar array systems. **FIG. 3** depicts an example of the differences in operation between a prior art Legacy system and the sonar sensor array **10** for a twenty-four hour period. In this example, the control signal circuitry **36** cycles the modes of operation between the low-resolution and high-resolution modes. In the Legacy system, the system operates constantly for twenty-four hours, all channels (i.e., all sonar sensors) are constantly powered. The amplitude scale of measurement is always 24 bits, the bandwidth is constantly 500 Hz, the sample rate is constantly 1250 SPS (samples/second), the power consumption is 100% and the data rate is 40 KB/SEC (kilobytes per second).

[0046] At the end of the operational period, the Legacy system records 3398 MB of data. This inefficient performance is contrasted with the very efficient operation of the sonar sensor array **10**. In this example, the sonar sensor array **10** is cycled between the low-resolution mode and the high-resolution mode. As

will be apparent by the data shown in **FIG. 3**; the low-resolution mode detects a suspected target ten times per day and the high-resolution mode is activated only for a ten-second period for each target detected during the low-resolution mode.

[0047] In this example, the sonar sensor array **10** is configured such that the sleep mode is not used and the control signal circuitry **36** cycles the operation between the low-resolution mode and high-resolution mode depending upon how many times the low-resolution mode detects a suspected target. As shown in **FIG. 3**, the low-resolution mode operates over a twenty-four hour period as does the Legacy system, but the low-resolution mode operates at periodic intervals wherein the duration of each period of low-resolution processing is one-hundred seconds in duration.

[0048] The low-resolution mode is implemented when the control signal circuitry **36** detects acoustic signals from powered sonar sensors **14**. A reduced number of the sonar sensors **14** are utilized in the low-resolution mode which yields a 5:1 reduction in active channels. The amplitude scale of measurement is eight bits, the bandwidth is 100 Hz and the sample rate is 250 SPS (samples/second). The power consumption in this mode is only ten percent of the power consumption of the prior art Legacy system. The resulting data rate is 0.73 KB/SEC and the amount of data actually recorded is 61.7 MB. If the low-resolution mode determines there is a target, then the control circuit **30** shifts the signal processing function to the high-resolution mode.

[0049] In the high-resolution mode, all of the sonar sensors **14** are powered (i.e., all channels are active), the amplitude scale of measurement is twenty-four bits, the sample rate is 1250 SPS (samples/second) and the data rate is 40KB/SEC. Although these operational characteristics are the same as the prior art Legacy system, the high-resolution mode is implemented for periods of ten seconds for each target detected by low-resolution mode processing. In this example, ten targets are detected in a twenty-four hour period. This means high-resolution mode processing occurs for a total of 100 seconds in a twenty-four hour period. During each ten-second period in which high-resolution mode processing is implemented, the power consumption is 100% and the data rate is 40 KB/SEC. However, the total amount of data collected in the high-resolution mode is 3.9 MB. As a result of cycling between the low-resolution and high-resolution modes, only 65.6 MB of data is recorded and the total power consumption over a twenty-four hour period is 10.1% of the total power consumed by the Legacy system over a twenty-four hour period.

[0050] In an alternate embodiment, the sonar sensor array **10** performs an initial spectral analysis of the acoustic signals detected by the sonar sensors **14** during low-resolution mode processing in order to confirm high-resolution mode processing is warranted. In such an embodiment, the sonar sensor array **10** includes a spectrum analysis device that processes the acoustic signals received by the sonar sensors **14** and outputs a signal for input into the control circuit **30** wherein such signal indicates

whether signal processing of the high-resolution mode is warranted.

[0051] The present invention provides many advantages and benefits. One advantage is the reduction in overall power consumption of the sonar sensor array; thereby, extending the lifetime of fixed capacity batteries. Another advantage is the significant reduction of the aggregate data bandwidth; thereby, resulting in relaxed data storage requirements and a decreased load on data processors or transmitters. Data having a low probability of containing signals of interest is either not recorded or is recorded at a reduced data rate; thereby, simplifying future data playback and processing tasks. As a result of the reduced amount of acquired data, lower bandwidth data-exfiltration techniques become viable.

[0052] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

[0053] The foregoing description of the preferred embodiments of the invention has been presented for purposes of illustration and description only. It is not intended to be exhaustive nor to limit the invention to the precise form disclosed; and obviously many modifications and variations are possible in light of the above teaching. Such modifications and variations that may be

apparent to a person skilled in the art are intended to be included within the scope of this invention as defined by the accompanying claims.

SONAR SENSOR ARRAY AND METHOD OF OPERATING SAME

ABSTRACT OF THE DISCLOSURE

A sonar sensor array is provided that has reduced power consumption, data bandwidth and data storage requirements. The sensor array may be configured to a sleep mode, low-resolution mode and high-resolution mode. In the sleep mode, all sonar sensors are configured in the sleep mode and no acoustic signals are detected. In the low-resolution mode, a limited number of sonar sensors are powered and acoustic signals received by the sonar sensors are processed with reduced bandwidth and reduced dynamic range, and then stored on a data storage device. In the high-resolution mode, the acoustic signals detected by the sonar sensors are processed with full signal bandwidth and full dynamic range and then stored on the data storage device.

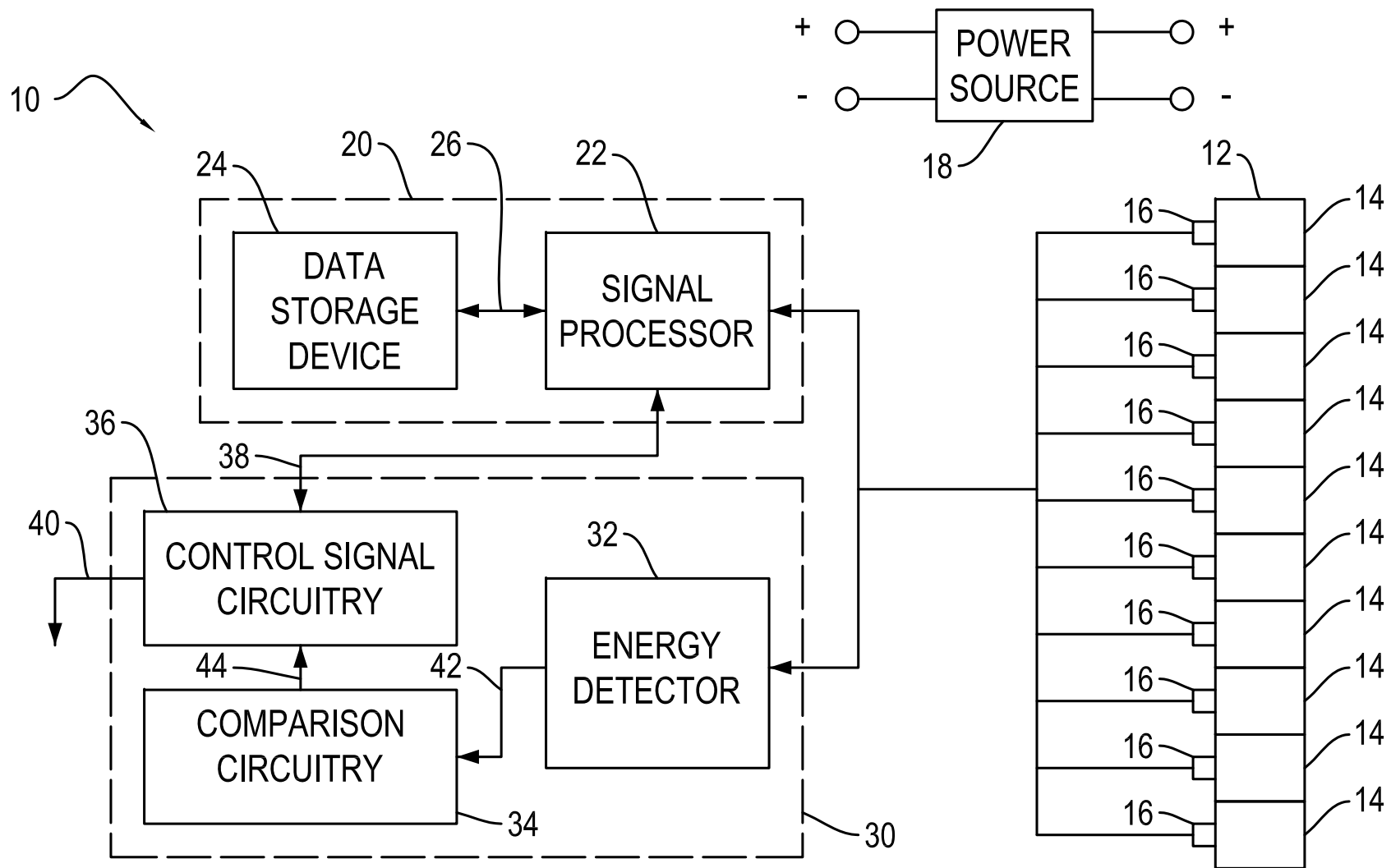


FIG. 1

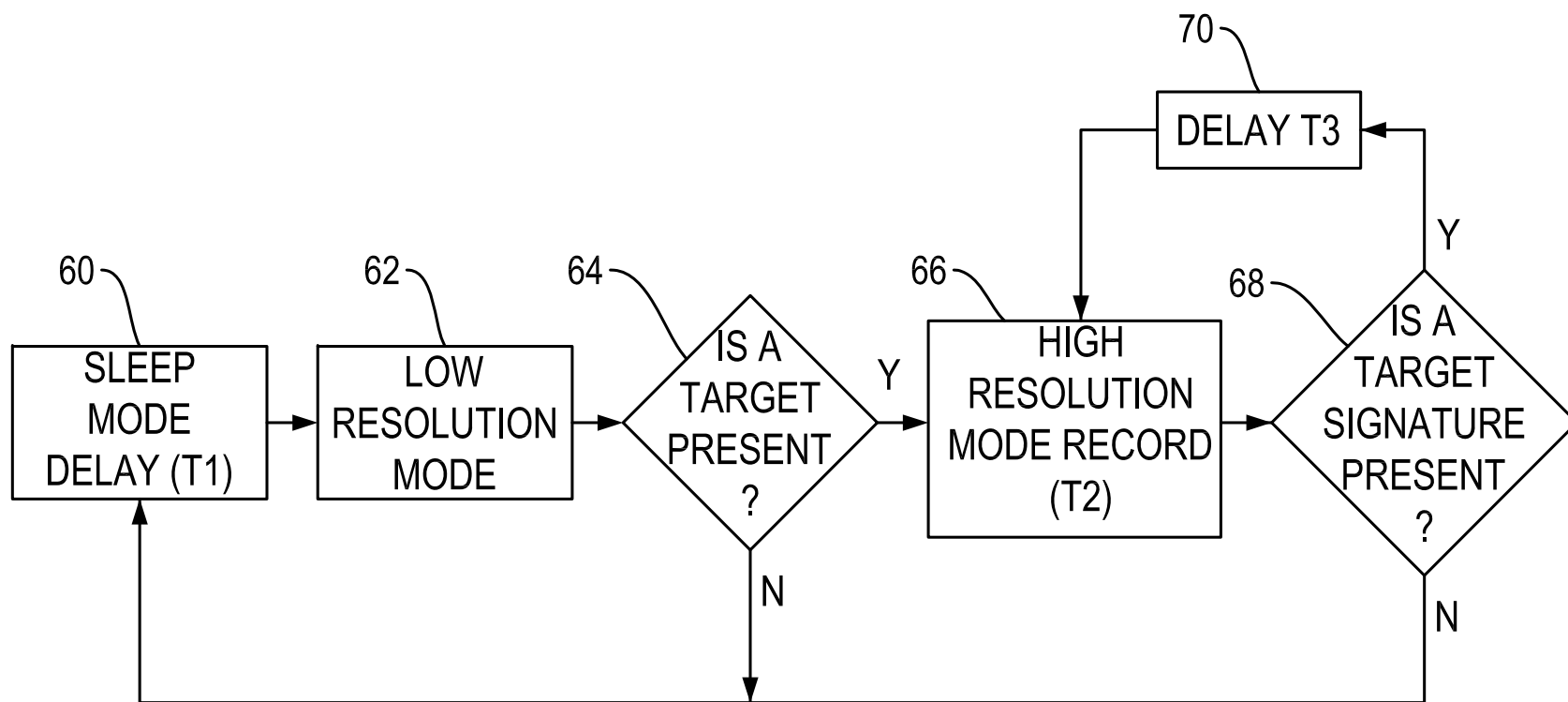


FIG. 2

	LEGACY MODE (PRIOR ART)	LOW-RESOLUTION	HIGH-RESOLUTION
CHANNELS	ALL CHANNELS ACTIVE	5:1 REDUCTION IN ACTIVE CHANNELS	ALL CHANNELS ACTIVE
DATA	24 BIT	8 BIT	24 BIT
BANDWIDTH	500 HZ	100 HZ	500 HZ
SAMPLE RATE	1250 SPS	250 SPS	1250 SPS
DURATION	24 HOURS	24 HOURS- 100 SECONDS	100 SECONDS
POWER CONSUMPTION	100%	10%	100%
DATA RATE	40 KB/SEC.	0.73 KB/SEC	40 KB/SEC.
DATA COLLECTED	3398 MB	61.7 MB	3.9 MB

FIG. 3